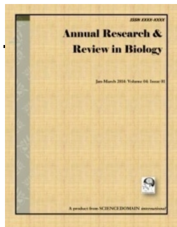

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Determination of Physical and Mechanical Properties of Autumn Leaves of Maple, Bitter Orange, Oak, Boxwood, Yellow Poplar, and Brown Poplar Trees

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Authors' contributions

This work was carried out in collaboration between all authors. Author AJ designed the study. Author AK collected the data and wrote the first draft of the manuscript. Author MA managed the analyses of the study and wrote the protocol. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Aims: The results will be used to design and construct a collecting device, specially the main sucking part.
Study Design: In order to determine the physical properties of autumn leaves, twenty leaves from each tree of maple, bitter orange, oak, boxwood, yellow poplar, and brown poplar were collected with the same shape found on the ground (wrinkled or crumpled).
Place and Duration of Study: Department of Agricultural Machinery, Faculty of Bio-System Engineering, University College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran, July and august 2012.
Methodology: The maximum length, width, and thickness, as well as mass of each leaf were measured in varied moisture, static friction coefficient, true density, bulk density, and porosity. To determine the mechanical properties of friction coefficient and discharge and filling angles, the limit velocity and shear strength were also measured in the leaves.
Results: Measurement of the leaves shear strength of maple, oak, bitter orange,

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boxwood, yellow poplar, and brown poplar showed the highest shear strength in brown poplar (0.085 MPa) and the lowest in maple (0.033 MPa). According to the measured aerodynamic properties of autumn leaves (maple, boxwood, yellow poplar, brown poplar, bitter orange, and oak), the velocity limit has increased by increasing moisture. The velocity limit increases by increasing moisture. Also the friction coefficient increased by increasing moisture.
Conclusion: Among the studied leaves, maple had the maximum mean of weight, the maximum length, and the maximum mean of thickness, while boxwood had the maximum density and the highest moisture. The highest and the lowest porosity belonged to maple leaves (96.17) and bitter orange leaves (95.88), respectively. The shear strength of maple, oak, bitter orange, boxwood, yellow poplar, and brown poplar leaves were 0.033, 0.034, 0.041, 0.038, 0.085, and 0.084 Mpa, respectively. The repose angle of filling and the angle of discharge of the six leaves in sum were 50° and 51°, respectively.

Keywords: Physical properties; mechanical properties; trees' leaves.

1. INTRODUCTION

Given the special emphasis on recycling and management of natural debris aiming to reduce environmental pollution, and on the other hand, looking always for ways to reduce the cost of compost production, many developed societies have extensive plans to collect fallen leaves. That is why many machines and devices have been developed over time to collect, compress, and break down easier and faster the natural debris [1-2].

Plant debris usually consists of leaves, stem, and bark. More than 80% of their dry matter is made of polysaccharide which is a resource of high potential energy. Leaves fallen on plants prevent adequate sunlight reaching them and decrease photosynthesis, resulting in reduced plant growth. In other words, failure to clean up fallen leaves from plants is a factor of plant disease [3].

Studies in the field of physical and mechanical properties of agricultural products can be classified into the following categories: 1- applying the basic principles of mechanics for mechanical behavior of agricultural materials; 2- implementation of approaches developed to describe behavior of agricultural materials basically for non-biologic (inanimate) materials [4]. Many researchers have tried to determine the physical properties of crops; of them the followings can be mentioned.

Moisture-dependent physical properties of agricultural products include shape, size, mass, true density, and bulk density [5]. Obtaining physical properties of crops is required for designing of equipment for their processing, transport, harvesting, and storage. Physical properties of crops are effective on characteristics of solids transfer by the flow of air and water as well as heating and cooling of food [6]. In a study in Australia, the physical properties of area, mass, density, and thickness of the leaves were examined in 8 trees and was shown that the maximum and minimum thickness belonged to Hakea Victoria and Spyridium Globuloswn, the maximum and minimum density to Bankisa Hakea and Victoria Speciosa, the maximum and minimum mass to Spyridium Globuloswn and Eualyptus Tetrogona, and the maximum and minimum area to Eualyptus Tetrogona and Spyridium Globuloswn, respectively [7].

Mechanical properties of leaves are obtained as follows:

The laboratory device for measuring shear strength consisted of an upper blade (mobile), a lower blade (fixed), two leaf holder clamps, a base on one side, and a scale connected to a computer which recorded the applied force on the scale with special software. The upper blade was moved toward the lower blade with a specified angle, velocity, and thickness. The up and down movement was performed with an electric motor and a belt and pulley system. During the experiments, the interaction of these factors on leaf shear strength was investigated following changes in the blade velocity and angle. The leaves shear strength can also be evaluated [8]. A study on grass shear strength showed that the tensile strength decreased by increasing moisture content and the values obtained were in the range of 108-294 MPa based on dry tolerance levels [9]. Grass shear tests showed that the shear strength and the shear energy were 16 MPa and 12 mJ/mm2, respectively [10]. When determining the amount of shear force of Cannabis sativa, the mean value of shear force and total shear energy of cannabis were 243 N and 2.1 J, respectively, [11]. Researcher reported that the cross section and moisture content of the product, have significant effect on the maximum shear force and shear energy [12-13]. Other researcher reported that the force required for cuting the long stems 50% less than that of soft stems [14]. Physical properties of plant stem at different heights above the ground are different. Therefore, determination of mechanical properties such as the strength of shear, bending and shear energy are necessary for proper design and operating parameters [15].

In this study, the maximum length, width, and thickness, as well as mass of each leaf were measured in varied moisture, static friction coefficient, true density, bulk density, and porosity. To determine the mechanical properties of friction coefficient and discharge and filling angles, the velocity limit and the shear strength were also measured in the leaves. The results will be used to design and construct a collecting device, specially the main sucking part.

2. MATERIALS AND METHODS

2.1 Geometrical Properties

To design leaf collecting device in this study, firstly the physical and mechanical properties of conventional leaves were measured. In order to determine the geometrical properties, twenty leaves from each tree of maple, bitter orange, oak, boxwood, yellow poplar, and brown poplar were collected with the same shape found on the ground (wrinkled or crumpled).

Then their maximum length, width, and thickness were measured with a caliper with a precision of 0.01 mm. Twenty leaves of each type were weighted with a digital scale with a precision of 0.001 g and put in a 100°C oven for twenty hours. The samples were then weighted again to find out their moisture content. The mass of each leaf was measured in varied moisture, static friction coefficient, true density, bulk density, and porosity.

2.2 Actual Density of the Leaves

The immersion method was used to determine the density of the material. To this end, a digital scale with a precision of 0.001 g was used. The leaves were weighed outdoors and recorded (M1), and then a water container was put on the scale and weighed (M2). Then the leaves, punctured with a needle, were immersed in water by a bar such that not collide with the side and weighed again (M3). The increase in weight due to immersion of the object is equal to the weight of displaced water, which is used in the equations to calculate volume and density [5].

$$V = \frac{M_{dw}}{\rho_w} \tag{1}$$

Where M_{dw} is the mass of displaced water (equal to $M_3 - M_2$) and ρ_W is the density of water. After calculating the volume, the density of leaf would be equal to Equation (2):

$$\rho = \frac{M_1}{V} \tag{2}$$

Leaf density can be calculated using Equation (3):

$$SG = \frac{M_1 \times SG_w}{M_{dw}} \tag{3}$$

SG_w is the density of water which is equal to one.

2.3 Leaf Shear Strength

Using laboratory equipment, a device was constructed (Fig. 1) which included an upper blade (mobile), a lower blade (fixed), two leaf holder clamps to fix the leaves, and a wooden board bridged between a base on one side and the scale on the other side. The precision of the scale was 0.01 g and it was connected to a computer which recorded the applied force on the scale with special software. The upper blade angle and thickness were considered 45° and 5 mm, respectively. The up and down movement of the upper blade was performed with an electric motor and a belt and pulley system such that the motor motion was transmitted to the blade through the belt and pulley. The velocity of the blade was selected approximately equal to 0.1 mm/s. It should be noted that the leaves were tightly fixed by the clamps at both sides to prevent spending of a part of the obtained force due to bending of the leaf.

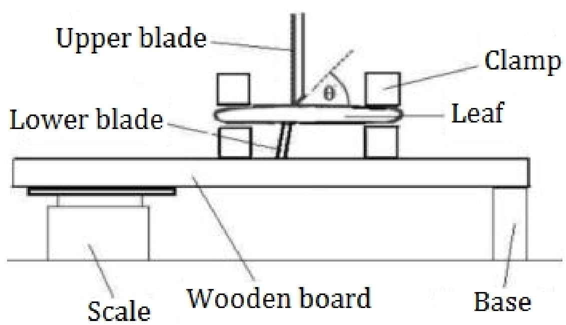

Fig. 1. Schema of the experiment to determine leaf shear strength

Given the existence of a balance force as Fig. (2), the force exerted on the scale was considered as the basis of calculation of leaf shear force.

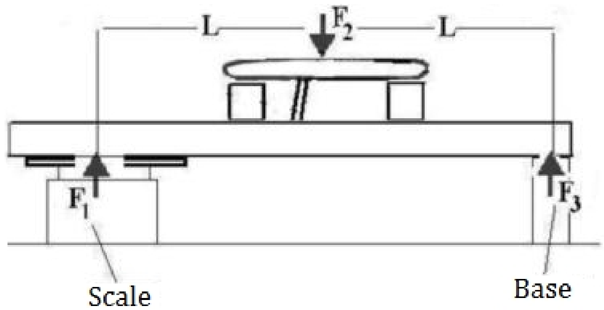

Fig. 2. Balance of action and reaction forces

F1: Force from scalepan on wooden board (equal to the force from wooden board to the scale), F2: Leaf shear force, F3: Force from base to the wooden board.

$$F_1 = F_3 \Rightarrow F_2 = 2 \times F_1$$

Therefore, the force measured by the scale is one half of the shear force. In this experiment, samples of maple and sycamore leaves, as the major leaf in urban green space, were tested. At first, the thickness of each leaf was measured with a micrometer. Then according to the distance between the clamps, each leaf was cut to patches of 3 and 5 cm such that the shear width was 3 cm. After tightening of each patch by the holder clamps on sides, the shear experiment was performed by the upper blade of the device in triplicate for each type of the leaves.

Then the forces measured by the scale and recorded by the software were collected and the shear strength of the leaves was obtained according to Equation (4).

$$\tau = \frac{F}{b.t} \tag{4}$$

τ Leaf shear strength (MPa), F: Leaf shear force (N), b: Leaf shear width (mm), t: Leaf thickness (mm).

2.4 Measurements of the Leaves Velocity Limit

In this study, the leaves velocity limit was measured through floating method; i.e. the leaves were released into a vertical pipe or wind tunnel where air flowed from bottom with a certain velocity (Fig. 3). The velocity of air flow within the pipe was adjusted to retain the object floating. The air velocity during leaf floatation was considered as the velocity limit of the object.

The air velocity near the location of the leaf floatation level was measured by a digital anemometer with a precision of 0.1 m/s. According to the leaves velocity limit, the minimum suction speed of the machine for collecting leaves can be obtained [5].

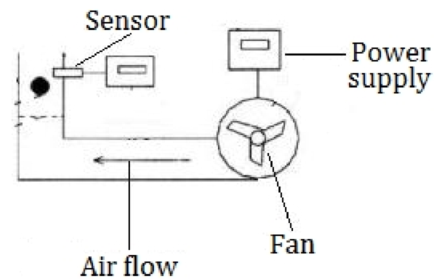

Fig. 3. Measurement of limit velocity through floating method

2.5 Discharge Angle

The discharge angle of the leaves was measured using a wooden box with a sliding door. At first, the box was filled with the material and then the sliding door was quickly drawn upward to discharge the material to the outside and a normal heap be formed inside the box. The purpose of this experiment was to identify the angle of leaves position inside the box.

The repose angle was obtained after measurement of the height at two points of the heap slope and the horizontal distance between these two points and then substituting in the equation (5) [16]. The discharge angle for maple leaf was calculated 49.9°.

$$\theta_e = \tan^{-1}[\frac{h_2 - h_1}{x_2 - x_1}] = 49.9^o \quad (5)$$

2.6 Filling Angle

The filling angle was measured using a wooden box as in Fig. (4). A channel was provided on the box through which the sample was descended from a certain altitude. Then the filling angle was obtained from the equation (6) [16]. The filling angle for maple leaf was calculated 50.96°.

$$\theta_f = \tan^{-1}[\frac{2h}{D}] = 50.96^o \quad (6)$$

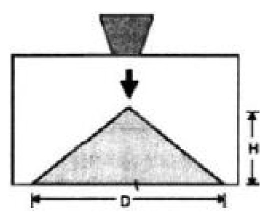

Fig. 4. Wooden box for measurement of the filling angle

3. RESULTS AND DISCUSSION

3.1 Physical Properties

The results of physical properties are given in Table 1.

Table 1. Physical properties of different leaves

Leaf properties	Leaf type					
	Bitter Orange	**Maple**	**Oak**	**Boxwood**	**Yellow Poplar**	**Brown Poplar**
Moisture (%)	11.28	5.87	18.02	34.01	11.5	8.79
Mean weight of 20 leaves (g)	0.4	0.57	0.5	0.25	0.46	0.47
Mean of length (mm)	9.04	10.95	9.94	5.15	7.28	7.81
Mean of width (mm)	4.73	10.11	4.54	2.55	6.84	7.9
Mean of thickness (mm)	0.27	0.28	0.25	0.22	0.27	0.28
Bulk density (kg/m^3)	25.4	17.21	25.6	26.2	23	22.1
Friction coefficient on iron	0.56	0.42	0.66	0.76	0.61	0.56
True density (kg/m^3)	617	450	640	675	560	545
Porosity	59.88	96.17	96	96.11	95.89	95.9

3.2 Shear Strength of the Leaves

Table 2 was prepared according to the results of the leaves shear strength determination.

Table 2. Results of the leaves shear strength experiment

Leaf type	Leaf thickness (mm)	Leaf shear width (mm)	Measured shear force (g. force)		
			First repeat	**Second repeat**	**Third repeat**
Maple	1	3	93	101.6	97.5
Oak	1	3	82	81.4	73
Bitter orange	0.27	3	30.3	30.4	33.5
Boxwood	0.22	3	21	25.6	23
Yellow poplar	0.27	3	69	61	58
Brown poplar	0.28	3	70	62.5	71

According to Equation (4), the shear strength of maple, oak, bitter orange, boxwood, yellow poplar, and brown poplar leaves was obtained according to the highest frequency in repeats of the results (Table 3). Although Yellow poplar and Brown poplar have the low thickness but because of their biological context, they have high shear strength.

Table 3. Results of the leaves shear strength experiment

Row	Leaf type	Shear strength (MPa)
1	Maple	0.033
2	Oak	0.034
3	Bitter orange	0.041
4	Boxwood	0.038
5	Yellow poplar	0.085
6	Brown poplar	0.084

According to Fig. (5), measurement of the leaves shear strength of maple, oak, bitter orange, boxwood, yellow poplar, and brown poplar showed the highest shear strength in brown poplar (0.085 MPa) and the lowest in maple (0.033 MPa).

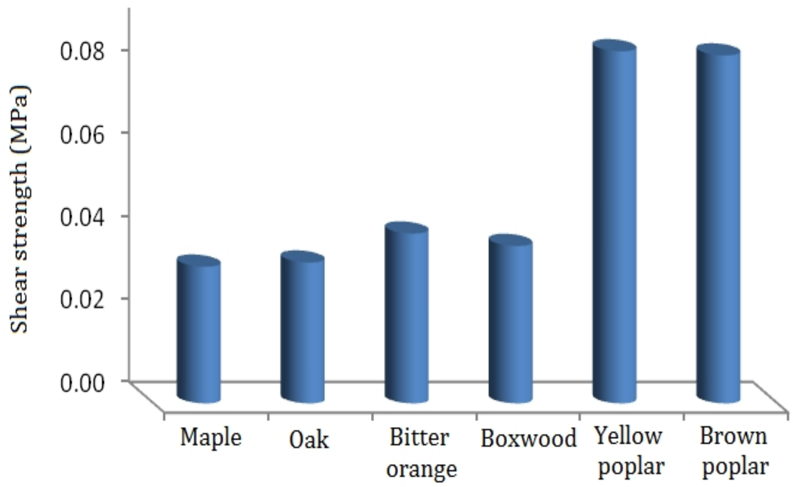

Fig. 5. Diagram of shear strength for different leaves

3.3 Leaves Velocity Limit versus Moisture

Table (4) depicts the velocity limit of the six species of leaf in various moisture contents. The minimum suction velocity of propeller of leaves collecting machine can be obtained using this physical property.

Table 4. Velocity limit of the six species of leaf moisture content

Leaf type	Quantity	Moisture content (db)	Velocity limit (m/s)
Maple	Maximum	21.7	2.32
	Minimum	5.52	1.11
Boxwood	Maximum	25.5	3.11
	Minimum	13.3	1.96
Yellow poplar	Maximum	12.56	1.94
	Minimum	6.14	1.2
Brown poplar	Maximum	11.98	1.83
	Minimum	8.01	1.42
Bitter orange	Maximum	18.73	2.96
	Minimum	12.27	1.85
Oak	Maximum	14.63	2.1
	Minimum	8	1.53

According to the measured aerodynamic properties of autumn leaves (maple, boxwood, yellow poplar, brown poplar, bitter orange, and oak), Fig. (6) shows that the velocity limit has increased by increasing moisture. The coefficient of determination is given in Table. In general, many studies have shown that velocity limit increases by increasing moisture.

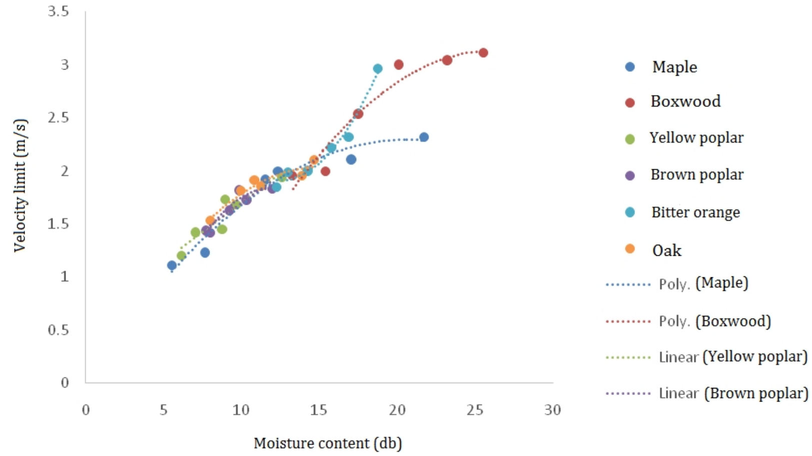

Fig. 6. Diagram of velocity limit versus leaf moisture

The coefficient of determination (R^2) and equations for the six leaves are depicted in Table (5). In general, many studies have shown that velocity limit increases by increasing moisture.

Table 5. Equation and coefficient of determination of the leaves

Leaf type	Equation	R^2
Maple	$y = -0.0079x^2 + 0.4141x - 2.2727$	0.9344
Boxwood	$y = -0.0054x^2 + 0.2238x - 0.018$	0.9581
Yellow poplar	$y = 0.1099\ x^2 + 0.5988$	0.8715
Brown poplar	y = -0.0262x2 + 0.6167x - 1.7968	0.9191
Bitter orange	y = 0.0264x2 - 0.6627x + 6.0623	0.976
Oak	y = -0.0094x2 + 0.2876x - 0.1483	0.917

3.4 Coefficient of Friction versus Moisture

In Fig. (7) the coefficient of friction of maple leaf on iron surface was plotted versus different contents. The diagram shows that the friction coefficient increases by increasing moisture.

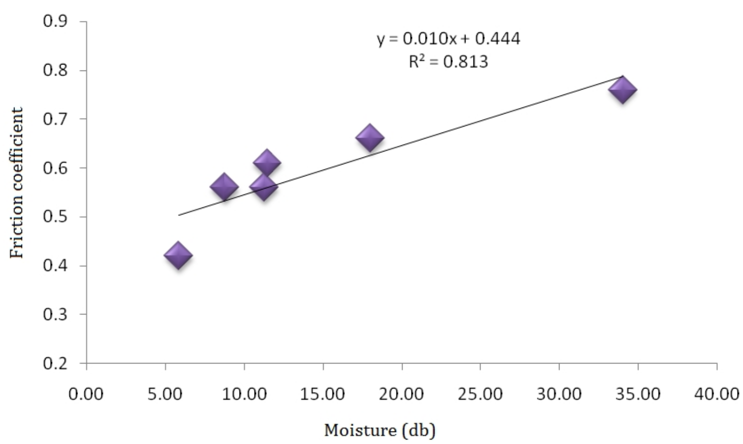

Fig. 7. Coefficient of friction versus moisture

3.5 Porosity

Fig. (8) depicts the diagram of porosity for different leaves. Given the geometry and surface properties of the leaves, as well as the plotted diagram, crushing of the leaves in leaf collecting machine is very ideal due to their high porosity.

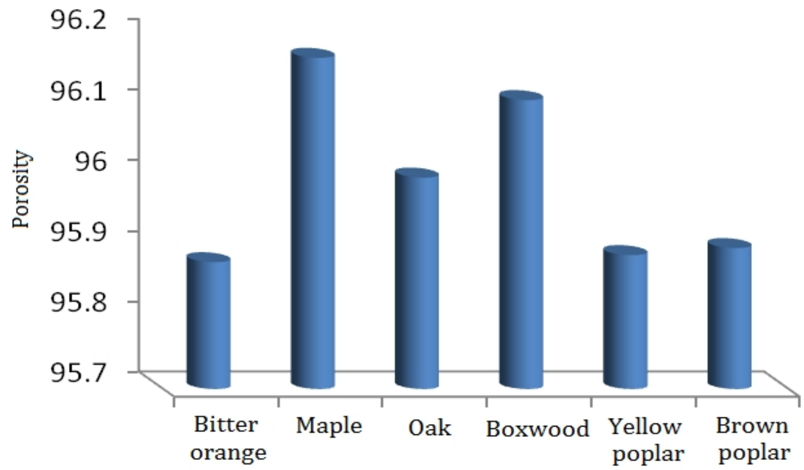

Fig. 8. Diagram of porosity for different leaves

4. CONCLUSION

Among the studied leaves, maple had the maximum mean of weight, the maximum length, and the maximum mean of thickness, while boxwood had the maximum density and the highest moisture. The coefficient of friction of leaves on iron surface was plotted versus the moisture content (Fig. 7) and its highest amount was seen in the boxwood leaves. The coefficient of determination was 81.35. This diagram shows that the friction coefficient increases by increasing moisture. The highest and the lowest porosity belonged to maple leaves (96.17) and bitter orange leaves (95.88), respectively; the porosity diagram was plotted for different leaves. According to the aerodynamic properties measured in leaves, it is observed that the velocity limit increases by increasing moisture content and the highest and lowest coefficient of determination were 88.28% for the leaves of bitter orange and 81.98% for the leaves of brown poplar, respectively. The shear strength of maple, oak, bitter orange, boxwood, yellow poplar, and brown poplar leaves were 0.033, 0.034, 0.041, 0.038, 0.085, and 0.084 Mpa, respectively. The repose angle of filling and the angle of discharge of the six leaves in sum were 50° and 51°, respectively.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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